

A COMPARISON OF ANTHROPOGENIC AND LONG-TERM SOIL EROSION ON BANKS PENINSULA USING ^{137}Cs AND KAWAKAWA TEPHRA

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1. Introduction

The task of this study is to assess the severity of anthropogenically induced soil erosion on a loess-mantled hillslope on the foothills of Banks Peninsula, South Island, New Zealand. The analysis is restricted to a slope segment representative for the soil creep-type processes that dominate on convex soil-mantled hillslopes which satisfy the assumptions of the soil erosion measurement techniques employed.

Convex hillslopes evolve through slope-dependent transport processes, such as creep, resulting from disturbance by expansion and contraction due to freeze-thaw, wet-dry and hot-cold cycles, by biologic activity, or – perhaps most significant for the current processes – by rain splash. The region has experienced climate changes and, consequently, changes in vegetation cover from forest to shrub vegetation and grassland (Shulmeister, 1999).

To quantify long-term (natural) and short-term (anthropogenically induced) erosion rates tracers within the soil are used. The thickness of soil above a ca. 26,500 year old tephra and an inventory of the amount of that tephra are used to determine the long-term rate across a convex hillslope, from the interfluvium to the midslope. An inventory of bomb-fallout ^{137}Cs is used to determine short-term rates over the same hillslope. A slope dependent transport model is parameterised to encapsulate transport efficiency relevant to the short and long time scales, and the parameters used as a basis for comparing soil erosion rates at different time scales. Comparing the results of the two different surveys, a statement is made whether the actual occurring erosion of soil under grass vegetation cover is higher than that under natural vegetation of the last 26,500 years.

2. Study Area

The hillslope chosen for this project is located on the loess-covered foothills in the west of Banks Peninsula, in the surroundings of Taitapu, in the South Island of New Zealand. The peninsula has been heavily eroded, and along the outer flanks steep-sided valleys have been incised and/or exhumed. These valleys, in combination with big gullies cut into the hillslopes, give Banks Peninsula the appearance of

a largely dissected surface with a general radial drainage pattern. Thereby, the rather low gradients of the radially diverging ridges contrast with the steep walls of the valleys.

The study site is a convex hillslope situated on a north aspect of a long ridge running in NE-SW direction. The hillslope transect studied was restricted to the upper convex slope segment from the interfluvium to the upper backslope. This section of the slope is characterised by low profile curvature and limited micro-topography. This restriction has been made because the soil creep-type processes presumed to dominate here (Gilbert, 1909; Dietrich et al., 2003) satisfy the assumptions of the ^{137}Cs erosion measurement techniques employed. Below the upper backslope, tunnel-gully erosion predominates and soil erosion rate is likely to be highly spatially and temporally variable.

3. Methodology

Long- and short-term erosion rates for the study area were quantified as follows:

- The hillslope transect was surveyed topographically at high resolution.
- Five sites were sampled along the transect and analysed for ^{137}Cs and tephra distribution and concentration. ^{137}Cs reference sites (uneroded) were sampled on the interfluvium.
- Short-term and long-term erosion rates were calculated for each site, using ^{137}Cs profile inventory, tephra grain inventory, and depth to tephra emplacement horizon.
- A slope dependent transport model was parameterised to encapsulate transport efficiency relevant to the short and long time scales, and the parameters used as a basis for comparing soil erosion rates at different time scales.

4. Modelling soil transport and erosion rate

The convex form of soil-mantled hillslopes results from slope-dependent soil transport (Gilbert, 1909), modelled one-dimensionally as

$$\bar{q}_s = -K \frac{\partial z}{\partial x} \quad (1)$$

where q_s is sediment flux [$\text{m}^3 \text{m}^{-1} \text{yr}^{-1}$], K the transport rate constant [$\text{m}^2 \text{yr}^{-1}$], $\partial z/\partial x$ the local hillslope gradient, z is elevation [m], and x the horizontal distance [m]. The one-dimensional form of the equation is used for clarity. The argument can be extended simply to the two-dimensional case.

As sediment flux on steep slopes tends to increase nonlinearly (Roering et al., 1999), this model is appropriate only for low-gradient (< 0.4) hillslopes (Roering et al., 2002). Combining equation (1) with the one-dimensional continuity equation,

$$E = \frac{\partial z}{\partial t} = \frac{\partial q_s}{\partial x}, \quad (2)$$

where E is erosion rate [m yr^{-1}], z is elevation [m], t is time [yr], q_s the sediment flux [$\text{m}^3 \text{m}^{-1} \text{yr}^{-1}$], and x is horizontal distance [m], gives

$$\frac{\partial z}{\partial t} = K * \frac{\partial^2 z}{\partial x^2}, \quad (3)$$

where $\partial^2 z/\partial x^2$ is local hillslope curvature.

This relationship indicates that erosion is proportional to local hillslope curvature, enabling to quantify variability in erosion rates, when coupled with the topographic survey of the hillslope. Thereby K is a constant of proportionality, the transport coefficient. This coefficient captures the efficiency of soil erosion, or the power of transport processing acting on the slope. A change in this parameter over different time scales is, therefore, a reflection of changes in intensity of erosion, as long as the slope dependent transport model is appropriate.

K can be estimated from the slope of a best fit line to a plot of erosion rate versus local hillslope curvature, or alternatively multiple values of K can be estimated from differences in erosion rates and curvatures from pairs of sites:

$$\Delta E_y = K * \Delta C_y, \quad (4)$$

where ΔE_y is the difference in erosion rate between sites i and j [m yr^{-1}] and ΔC_y the difference in curvature between sites i and j [m^{-1}].

5. Results and discussion

Long-term erosion rates, as quantified by tephra distribution along the hillslope, appear to be proportional to hillslope curvature, confirming the appropriateness of a slope dependent transport model. The transport coefficient calculated over the long term ($K_{\text{long}} = 0.0032 \pm 0.0007 \text{ m}^2 \text{yr}^{-1}$) is in the range of the estimates in similar studies (Roering et al., 2002; Walther, 2006).

Any difference between long- and short-term erosion rates would be captured in differences in K_{long} and K_{short} .

Unfortunately, the level of variability of the ^{137}Cs -based short-term erosion rates does not allow an assessment of the appropriateness of the slope-dependent transport model over the short term, and it prevents a meaningful estimate of K_{short} being made. An analysis of power of the regression analysis suggests as many as 20 observations would be necessary to determine a statistically significant slope (at 95 % confidence) when K_{short} is approximately equal to K_{long} . If K_{short} was higher, fewer observations would be necessary.

Actually, rather than on the upper part of convex hillslopes, significant erosion processes seem to be concentrated in areas of tunnel-gullies on the lower backslopes and incised valleys on the ridges of Banks Peninsula. These tunnel-gullies are propagating back up and lead to evident soil loss. To quantify the dimension of this soil loss, further studies either on the same ridge or on similar ridges should be carried out using e.g. the above mentioned techniques or the volumetric analysis of the sediment fan at the outlet of a gully. This would also enable to get more insights in the sediment yield of such a ridge and probably in the quantitative relation between soil loss on the upper backslope and in the gullies.

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